

# Recovery phase of magnetic storms induced by different interplanetary drivers

Yu. I. Yermolaev,<sup>1</sup> I. G. Lodkina,<sup>1</sup> N. S. Nikolaeva,<sup>1</sup> M. Yu. Yermolaev<sup>1</sup>

---

<sup>1</sup>Space Plasma Physics Department,  
Space Research Institute, Russian Academy  
of Sciences, Profsoyuznaya 84/32, Moscow  
117997, Russia. (yermol@iki.rssi.ru)

arXiv:1111.6914v1 [physics.space-ph] 29 Nov 2011

**Abstract.**

Statistical analysis of *Dst* behaviour during recovery phase of magnetic storms induced by different types of interplanetary drivers is made on the basis of OMNI data in period 1976-2000. We study storms induced by ICMEs (including magnetic clouds (MC) and Ejecta) and both types of compressed regions: corotating interaction regions (CIR) and Sheaths. The shortest, moderate and longest durations of recovery phase are observed in ICME-, CIR-, and Sheath-induced storms, respectively. Recovery phases of strong ( $Dst_{min} < -100$  nT) magnetic storms are well approximated by hyperbolic functions  $Dst(t) = a/(1 + t/\tau_h)$  with constant  $\tau_h$  times for all types of drivers while for moderate ( $-100 < Dst_{min} < -50$  nT) storms *Dst* profile can not be approximated by hyperbolic function with constant  $\tau_h$  because hyperbolic time  $\tau_h$  increases with increasing time of recovery phase. Relation between duration and value  $Dst_{min}$  for storms induced by ICME and Sheath has 2 parts:  $Dst_{min}$  and duration correlate at small durations while they anticorrelate at large durations.

## 1. Introduction

Dynamics of a magnetic storm is result of competing processes: excitation and relaxation [Burton *et al.*, 1975]. Generation of magnetic storm is connected with southward ( $Bz < 0$ ) component of interplanetary magnetic field (IMF) (or interplanetary electric field  $Ey = Vx \times Bz$ , where  $V$  is solar wind velocity) [Dungey, 1961; Fairfield and Cahill, 1966; Rostoker and Falthammar, 1967; Russell *et al.*, 1974; Burton *et al.*, 1975; Akasofu, 1981]. Relaxation of magnetic storm is connected with ring current decay [Daglis *et al.*, 1999]. The relation between excitation and relaxation changes during storm development: excitation process prevails over relaxation process at the main phase while the relaxation prevails at the recovery phase.

As well known, large and long component  $Bz < 0$  in the interplanetary space is observed only in disturbed types of solar wind. Therefore interplanetary drivers of magnetic storms are the following disturbed types of solar wind: (1) CIR (Corotating Interaction Regions) formed in compress region between slow and high-speed streams of solar wind, (2) ICME (interplanetary coronal mass ejections including magnetic clouds and less powerful disturbance - Ejecta), and (3) Sheath formed in compress region between fast ICME and slower stream of solar wind (see reviews and recent papers, for instance, by Tsurutani and Gonzalez [1997]; Gonzalez *et al.* [1999]; Yermolaev and Yermolaev [2006]; Zhang *et al.* [2007]; Turner *et al.* [2009]; Yermolaev *et al.* [2010b, 2011]; Nikolaeva *et al.* [2011]; Gonzalez *et al.* [2011]; Guo *et al.* [2011] and references therein). One of recent important experimental results is evidence that features of magnetic storm depend on type of the interplanetary driver [Borovsky and Denton, 2006; Denton *et al.*, 2006; Huttunen *et al.*,

2006; *Pulkkinen et al.*, 2007a; *Plotnikov and Barkova*, 2007; *Longden et al.*, 2008; *Turner et al.*, 2009; *Yermolaev et al.*, 2010b; *Guo et al.*, 2011] These facts indicate that mechanisms of magnetic storm generation (or modes of these mechanisms) can differ depending on the driver.

It is usually considered that decay of the ring current depends exclusively on internal processes (charge exchange, Coulomb collision, wave-particle interaction, and drift loss) and current interplanetary conditions (see, for instance, *Daglis et al.* [1999]; *Keika et al.* [2006]; *Xu and Du* [2010]. and references therein) In this paper we study time variation of *Dst* index during recovery phase of magnetic storms induced by different interplanetary drivers, i.e. dependence of *Dst* profile on conditions which were in interplanetary space during the main phase.

In accordance with formula by *Burton et al.* [1975] the *Dst* index should grow with exponential law at recovery phase. Many papers showed that for *Dst* profile approximation it is necessary to use exponential time ( $\tau_e$ ) which changes with time and depends on minimum *Dst* index [*OBrien and McPherron*, 2000; *Feldstein et al.*, 2000; *Monreal MacMahon and Llop-Romero*, 2008; *Xu and Du*, 2010]. *Aguado et al.* [2010] indicated that *Dst* profile can be approximate by hyperbolic function  $Dst(t) = Dst_0/(1 + t/\tau_h)$  with constant hyperbolic time  $\tau_h$ . In our analysis we use hyperbolic approximation as simpler one because our aim is to search for difference of *Dst* profile for storms generated by various interplanetary drivers and type of approximation function is not important for this aim.

## 2. Methods

In order to study the problem we use OMNI data of solar wind and interplanetary magnetic field parameters (see <http://omniweb.gsfc.nasa.gov> [King and Papitashvili, 2004]) and data on *Dst* index (see <http://wdc.kugi.kyoto-u.ac.jp/index.html>), as well as our catalog of large-scale interplanetary events for period of 1976–2000 (see <ftp://www.iki.rssi.ru/pub/omni> [Yermolaev et al., 2009]). We study moderate and strong magnetic storms with  $-100 < Dst_{min} \leq -50$  nT and  $Dst_{min} < -100$  nT, respectively. The technique of determination of connection between magnetic storms and their interplanetary drivers consists in the following. If the minimum of *Dst* index lies in an interval of a type of solar wind streams or is observed within 1–2 hours after it we believe that the given storm has been generated by the given type of streams [Yermolaev et al., 2010a]. Our analysis for period of 1976–2000 showed that 145 magnetic storms (31.2% from total number of identified storms) have been generated by CIR, 96 (20.7%) storms by Sheath, 62 (16.0%) by MC and 161 (34.7%) by Ejecta. The sources of other 334 magnetic storms (i.e., 42% of 798 storms observed during this time interval) are indeterminate and these storms are indicated as IND [Yermolaev et al., 2010a, 2012]. About 20% of storms were multistep ones during recovery phase and these storms were excluded from analysis.

It should be noted that average duration of main phase of magnetic storm is about  $7 \pm 4$  hours and it is less than average durations of interplanetary drivers:  $24 \pm 11$  h for MC,  $29 \pm 5$  h for Ejecta,  $16 \pm 3$  h for Sheath before Ejecta,  $9 \pm 5$  h for Sheath before MC, and  $20 \pm 4$  h for CIR [Yermolaev et al., 2007, 2010a]. Therefore the main phase for the majority of magnetic storms may be completely defined by one type of solar wind streams and it is possible to consider that a storm is connected with one interplanetary driver. In

contrast with main phase, the recovery phase can last up to 3 days, i.e. it is longer than duration of interplanetary drivers. Therefore only at initial (short in comparison with full phase) stage of recovery phase the interplanetary conditions may correspond to that driver which operated at the main phase, and at the subsequent stage of recovery phase type of solar wind streams is replaced by another types: Fast follows CIR, MC or Ejecta follow Sheath, Fast or Slow streams follows MC and Ejecta. Change of type of solar wind during recovery phase is not analyzed in the given work, and we classify storms only on their drivers operating at the main phase of storm.

One of the difficulties of recovery phase analysis is definition of time when the phase comes to its end as  $Dst$  index quickly grows at the first stage, and then the growth slows down at approach to the initial undisturbed level, and there is large (up to 20%)  $Dst$  variation which is not connected with general process of storm evolution. We use times when  $Dst$  index achieves levels of  $1/2$  and  $1/3$  from minimum  $Dst$  index as criteria of time of recovery phase termination, and analyze two durations  $\Delta t_{1/2}$  and  $\Delta t_{1/3}$ , i.e. time intervals from  $Dst_{min}$  up to  $(1/2)Dst_{min}$  ( $\Delta t_{1/2} = t((1/2)Dst_{min}) - t(Dst_{min})$ ) and  $(1/3)Dst_{min}$  ( $\Delta t_{1/3} = t((1/3)Dst_{min}) - t(Dst_{min})$ ), respectively. Comparison of two data sets corresponding to  $\Delta t_{1/2}$  and  $\Delta t_{1/3}$  allows us to make conclusions about dynamics of  $Dst$  index during storm recovery phase.

### 3. Results

Histograms of recovery phases durations  $\Delta t_{1/2}$  (black line) and  $\Delta t_{1/3}$  (gray line) for the storms generated by various drivers are shown in Figure 1. All distributions  $\Delta t_{1/2}$  have peaks in range of 6–12 hours, some events in range of 0–6 hours and long tails in range of large times. In contrast with  $\Delta t_{1/2}$ , character of distribution  $\Delta t_{1/3}$  depends on type of

drivers. For Ejecta and MC (and their sum) distributions have a maximum in range of 12–18 hours, approximately half of maximum in range of 6–12 hours and sharply falling down tail:  $\sim 1/10$  of maximum for Ejecta and  $\sim 1/3$  for MC at 42 hours. Histogram for CIR has a maximum in range of 24–30 hours and wide distribution. For Sheath there are 2 maxima at 12–24 hours (this maximum is similar to maximum Ejecta and MC) and 36–42 hours and wide distribution. IND-storms (with not identified sources) have the distribution similar to the sum of mentioned above distributions. Mean values and standard deviations of durations of recovery phases for both  $\Delta t_{1/2}$  and  $\Delta t_{1/3}$  and for all types of drivers (see Table 1) quantitatively support features of Figure 1. Thus, both figure and table show that distributions differ for ICME and compressed types of drivers. At transition from  $\Delta t_{1/2}$  to  $\Delta t_{1/3}$  distributions for Ejecta and MC (and their sum) are simply displaced towards longer durations with distribution form preservation (sharp maximum at small durations and monotonously falling down tail in the range of large durations), while CIR- and Sheath-induced storms qualitatively change the shape of distributions (larger time of maxima and wider distributions).

Figure 2 shows  $Dst$  profiles during recovery phase of strong ( $Dst_{min} < -100$  nT) magnetic storms induced by various drivers, and their approximations by hyperbolic functions (approximation coefficients are presented in Table 2). Data for every type of drivers were obtained by method of superposed epoch analysis with zero (epoch) time equal to time of  $Dst_{min}$ . All profiles are well approximated in region of 0–48 hours, the largest time  $\tau_h$  is observed for Sheath-induced storms and the smallest  $\tau_h$  for ICME-induced storms. Unlike strong storms, moderate storms (see Figure 3) for all drivers have a characteristic break in range of 10–15 hours, and they cannot be described by hyperbolic function with constant

$\tau_h$  (or exponential function with constant  $\tau_e$ ). For example, we show in Figure 3a, 3b and 3c results of approximation in ranges of 0–11, 0–18 and 0–48 hours, respectively, and we present approximation coefficients in the Table 2. For all approximation regions time  $\tau_h$  is the largest for Sheath-induced storms and the least for ICME-induced storms.

In order to investigate how duration of storm recovery phase depends on value  $Dst_{min}$ , we calculate average  $|Dst_{min}|$  values for each type of drivers in 6-h bins, and results are shown in Figure 4. Panels 4a and 4b show results for durations  $\Delta t_{1/2}$  and  $\Delta t_{1/3}$ , respectively. For all types of storms on the average the size of storms grows in a range from 4 till 18 hours for  $\Delta t_{1/2}$  durations and in a range of 6–30 hours for  $\Delta t_{1/3}$ , and falls with increasing duration. For  $\Delta t_{1/3}$  the size of storms is practically a constant for duration longer 48 hour, i.e. it does not depend on duration. Near maxima  $|Dst_{min}|$  stronger storms were induced by Sheath and MC, Ejecta-induced storms have moderate peak and CIR-induced storms have weak maximum. It should be noted that maxima  $|Dst_{min}|$  on both panels are statistically significant (see Figure 1). Thus, there are 2 branches of  $Dst_{min}$  versus duration dependence: increasing and decreasing ones.

#### 4. Discussion and conclusions

On the basis of OMNI data of plasma and IMF parameters of solar wind during 1976–2000 we classified various types of solar wind streams and found interplanetary drivers for 572 magnetic storms. These data allowed us to compare temporal evolution of  $Dst$  index during recovery phase of magnetic storms induced by CIR, Sheath and ICME (including MC and Ejecta). Our study allowed to obtain following results.

1. As distributions of duration of recovery phases show (see Figure 1 and Table 1), initial parts of recovery (distributions of  $\Delta t_{1/2}$ ) are close to each other for all types of



drivers, and at further part of recovery ( $\Delta t_{1/3}$ ) distributions differ and histograms are wider (i.e. on the average recovery is slower) for compression regions Sheath and CIR than for both types of ICME.

2. Dst index during recovery phase is well approximated by hyperbolic functions  $Dst(t) = a/(1 + t/\tau_h)$  only for strong ( $Dst_{min} < -100$  nT) storms. This result is in good agreement with conclusions by *Aguado et al.* [2010]. Approximation shows that the hyperbolic index  $\tau_h$  is the greatest for Sheath- (the slowest recovery), intermediate for CIR- and the least for ICME-induced storms (Figure 2 and Table 2).

3. In contrast to strong storms, Dst index during recovery phase is bad approximated by hyperbolic functions for moderate storms with  $-100 < Dst_{min} \leq -50$  nT and hyperbolic index  $\tau_h$  depends on time of recovery phase. Approximation in regions of 0–11, 0–18, and 0–48 hours (see Figure 3) shows that dependence of hyperbolic index  $\tau_h$  on type of drivers is similar to dependence for strong storms.

4. For storms generated by ICME and Sheath, there are 2 classes of storms (see Figure 4): duration of recovery phase and  $Dst_{min}$  correlate for short storm duration and they have inverse correlation for long storm duration. For storms generated by CIR, duration of recovery phase of storm does not depend on  $Dst_{min}$ .

Thus obtained results allow us to conclude that recovery phase  $Dst$  variations depend on type of interplanetary drivers inducing magnetic storms and magnetosphere remember type of driver during recovery phase.

**Acknowledgments.** The authors are grateful for the possibility of using the OMNI database. The OMNI data were obtained from the GSFC/SPDF OMNIWeb on the site <http://omniweb.gsfc.nasa.gov>. This work was supported by the Russian Foundation for

Basic Research, projects nos. 07-02-00042 and 10-02-00277a, and by the Program 16 of Physics Department of Russian Academy of Sciences (OFN RAN).

## References

- Aguado J., C. Cid, E. Saiz, and Y. Cerrato, (2010), Hyperbolic decay of the Dst Index during the recovery phase of intense geomagnetic storms, *J. Geophys. Res.*, VOL. 115, A07220, doi:10.1029/2009JA014658, 2010
- Akasofu, S.-I. (1981), Energy coupling between the solar wind and the magnetosphere, *Space Sci. Rev.*, 111, A07S08, doi:10.1029/2005JA011447.
- Borovsky, J. E. and Denton, M.H. (2006), Differences between CME-Driven Storms and CIR-Driven Storms, *J. Geophys. Res.*, 28, 121–190.
- Burton, R. K., McPherron, R. L., and Russell, C. T (1975), An empirical relationship between interplanetary conditions and Dst, *J. Geophys. Res.*, 80, 4204–4214.
- Daglis I., Thorne R. M., Baumjohann W., et al. (1999), The terrestrial ring current: origin, formation, and decay, *Rev. Geophys.*, 37, 407–438.
- Denton, M. H., Borovsky, J. E., Skoug, R. M., Thomsen, M. F., Lavraud, B., Henderson, M. G., McPherron, R. L., Zhang, J. C., and Liemohn, M. W. (2006), Geomagnetic storms driven by ICME and CIR-dominated solar wind, *J. Geophys. Res.*, 111, A07S07, doi:10.1029/2005JA011436.
- Dungey, J. W. (1961), Interplanetary Magnetic Field and the Auroral Zones, *Phys. Rev. Lett.*, 6, 47–48.
- Fairfield, D. H. and Cahill, Jr., L. J. (1966), The transition region magnetic field and polar magnetic disturbances, *J. Geophys. Res.*, 71, pp.155–169.

- Feldstein, Y. I., L. A. Dremukhina, U. Mall, and J. Woch, (2000), On the two-phase decay of the Dst-variation, *Geophys. Res. Lett.*, 27(17),28132816, doi:10.1029/2000GL003783.
- Gonzalez, W. D., Tsurutani, B. T., and Clua de Gonzalez, A. L. (1999), Interplanetary origin of geomagnetic storms, *Space Sci. Rev.*, 88, 529–562.
- Gonzalez W. D., E. Echer, B. T. Tsurutani, A. L. Clua de Gonzalez, A, Dal Lago, (2011), Interplanetary Origin of Intense, Superintense and Extreme Geomagnetic Storms, *Space Sci Rev*, 158, 69–89. DOI 10.1007/s11214-010-9715-2
- Guo, J., X. Feng, B. A. Emery, J. Zhang, C. Xiang, F. Shen, and W. Song (2011), Energy transfer during intense geomagnetic storms driven by interplanetary coronal mass ejections and their sheath regions, *J. Geophys. Res.*, 116, A05106, doi:10.1029/2011JA016490
- Huttunen, K.E.J., Koskinen, H.E.J., Karinen, A., and Mursula, K. (2006), Asymmetric Development of Magnetospheric Storms during Magnetic Clouds and Sheath Regions, *Geophys. Res. Lett.*, vol. 33, p. L06107.doi: 10.1029/2005GL024894.
- Keika K., Nose M., Brandt P. C., et al. (2006), Contribution of charge exchange loss to the storm time ring current decay: IMAGE/HENA observations, *J. Geophys. Res.*, vol. 111: A11S12, doi:10.1029/2006JA011789:
- King, J.H. and Papitashvili, N.E., (2004), Solar Wind Spatial Scales in and Comparisons of Hourly Wind and ACE Plasma and Magnetic Field Data, *J. Geophys. Res.*,vol. 110, no. A2, p. A02209. doi: 10.1029/2004JA010804.
- Longden, N., Denton, M.H., and Honary, F., (2008), Particle Precipitation during ICME-Driven and CIR-Driven Geomagnetic Storms, *J. Geophys. Res.*, vol. 113, p. A06205. doi: 10.1029/2007JA012752. 2008.

- Monreal MacMahon, R. and Llop-Romero, C.(2008), Ring current decay time model during geomagnetic storms: A simple analytical approach, *Ann.Geophys.*, 26, 2543–2550.
- Nikolaeva, N. S., Yu. I. Yermolaev, and I. G. Lodkina, (2011), Dependence of Geomagnetic Activity during Magnetic Storms on the Solar Wind Parameters for Different Types of Streams, *Geomagnetism and Aeronomy*, Vol. 51, No. 1, pp. 49–65. (*Geomagnetizm i Aeronomiya*, 2011, Vol. 51, No. 1, pp. 51–67.)
- O'Brien, T. P., and R. L. McPherron, (2000), An empirical phase space analysis of ring current dynamics: Solar wind control of injection and decay, *J. Geophys. Res.*, 105 (A4), 7707–7719, doi:10.1029/1998JA000437.
- Plotnikov, I. Ya. and Barkova, E.S., (2007), Nonlinear Dependence of Dst and *AE* Indices on the Electric Field of Magnetic Clouds, *Adv. Space Res.*, vol. 40, p. 1858.
- Pulkkinen, T. I., Partamies, N., Huttunen, K. E. J., Reeves, G. D., and Koskinen, H. E. J., (2007a), Differences in geomagnetic storms driven by magnetic clouds and ICME sheath regions, *Geophys. Res. Lett.*, 34, L02105, doi:10.1029/2006GL027775.
- Rostoker, G. and Falthammar, C.-G., (1967), Relationship between changes in the interplanetary magnetic field and variations in the magnetic field at the earth's surface, *J. Geophys. Res.*, 72, pp. 5853–5863.
- Russell, C. T., McPherron, R. L., and Burton, R. K., (1974), On the cause of magnetic storms, *J. Geophys. Res.*, 79, 1105–1109.
- Tsurutani, B. T. and Gonzalez, W. D. (1997), The interplanetary Causes of Magnetic Storms: A Review, in: *Magnetic Storms*, edited by: Tsurutani, B. T., Gonzalez, W. D., and Kamide, Y., Amer. Geophys. Union Press, Washington D.C., Mon. Ser., 98, p. 77, 1997.

- Turner, N. E., Cramer, W.D., Earles, S.K., and Emery, B.A., (2009), Geoefficiency and Energy Partitioning in CIR-Driven and CME-Driven Storms, *J. of Atmosph. and Sol.-Terrest. Phys.*, vol. 71, pp. 1023–1031.
- Xu Wen-Yao, Du Ai-Min, (2010), Effects of the ring current decay rate on the energy state of the magnetosphere, *Chinese J. Geophysics*. Vol.53, No.3, pp: 329–338
- Yermolaev, Yu. I. and M. Yu. Yermolaev, (2006), Statistic Study on the Geomagnetic Storm Effectiveness of Solar and Interplanetary Events, *Adv. Space Res.* 37 (6), 1175–1181.
- Yermolaev, Yu. I., Yermolaev, M. Yu., Nikolaeva, N. S., and Lodkina, L. G. (2007), Interplanetary conditions for CIR-induced and MC induced geomagnetic storms, *Bulg. J. Phys.*, 34, 128–135.
- Yermolaev, Yu. I., et al., (2009), Catalog of Large-Scale Solar Wind Phenomena during 1976–2000, *Kosm. Issled.*, vol. 47, no. 2, pp. 99–113. [*Cosmic Research*, pp. 81–94].
- Yermolaev, Yu. I., N. S. Nikolaeva, I. G. Lodkina, and M. Yu. Yermolaev, (2010a), Relative Occurrence Rate and Geoeffectiveness of Large-Scale Types of the Solar Wind, *Kosmicheskie Issledovaniya*, Vol. 48, No. 1, pp. 3–32. (*Cos. Res.*, 2010, Vol. 48, No. 1, pp. 1–30).
- Yermolaev, Yu. I., N. S. Nikolaeva, I. G. Lodkina, and M. Yu. Yermolaev, (2010b), Specific interplanetary conditions for CIR-, Sheath-, and ICME-induced geomagnetic storms obtained by double superposed epoch analysis, *Ann. Geophys.*, 28, 2177–2186.
- Yermolaev, Yu.I., I.G. Lodkina, N.S. Nikolaeva, M.Yu. Yermolaev, (2011), Statistical Study of Interplanetary Condition Effect on Geomagnetic Storms: 2. Variations of Parameters, *Cosmic Research*, Vol. 49, No. 1, pp. 21–34.

**Table 1.** Average values and standard deviations of recovery phase durations.

Types of drivers	$\Delta t_{1/2}^a$		$\Delta t_{1/3}^b$	
	Durations, h	Number	Durations, h	Number
IND	$17.1 \pm 9.9$	296	$31.3 \pm 17.0$	288
CIR	$16.1 \pm 9.8$	108	$33.4 \pm 18.0$	102
Ejecta	$14.8 \pm 7.0$	130	$25.9 \pm 14.1$	128
MC	$16.3 \pm 9.0$	57	$25.0 \pm 12.2$	57
MC + Ejecta (ME)	$15.3 \pm 7.7$	187	$25.6 \pm 13.5$	185
Sheath	$18.6 \pm 11.3$	86	$31.6 \pm 16.6$	85

$$^a \Delta t_{1/2} = t(1/2Dst_{min}) - t(Dst_{min})$$

$$^b \Delta t_{1/3} = t(1/3Dst_{min}) - t(Dst_{min})$$

**Table 2.** Approximation of Dst profiles by hyperbolic function  $Dst(t) = a/(1 + t/\tau_h)$ 

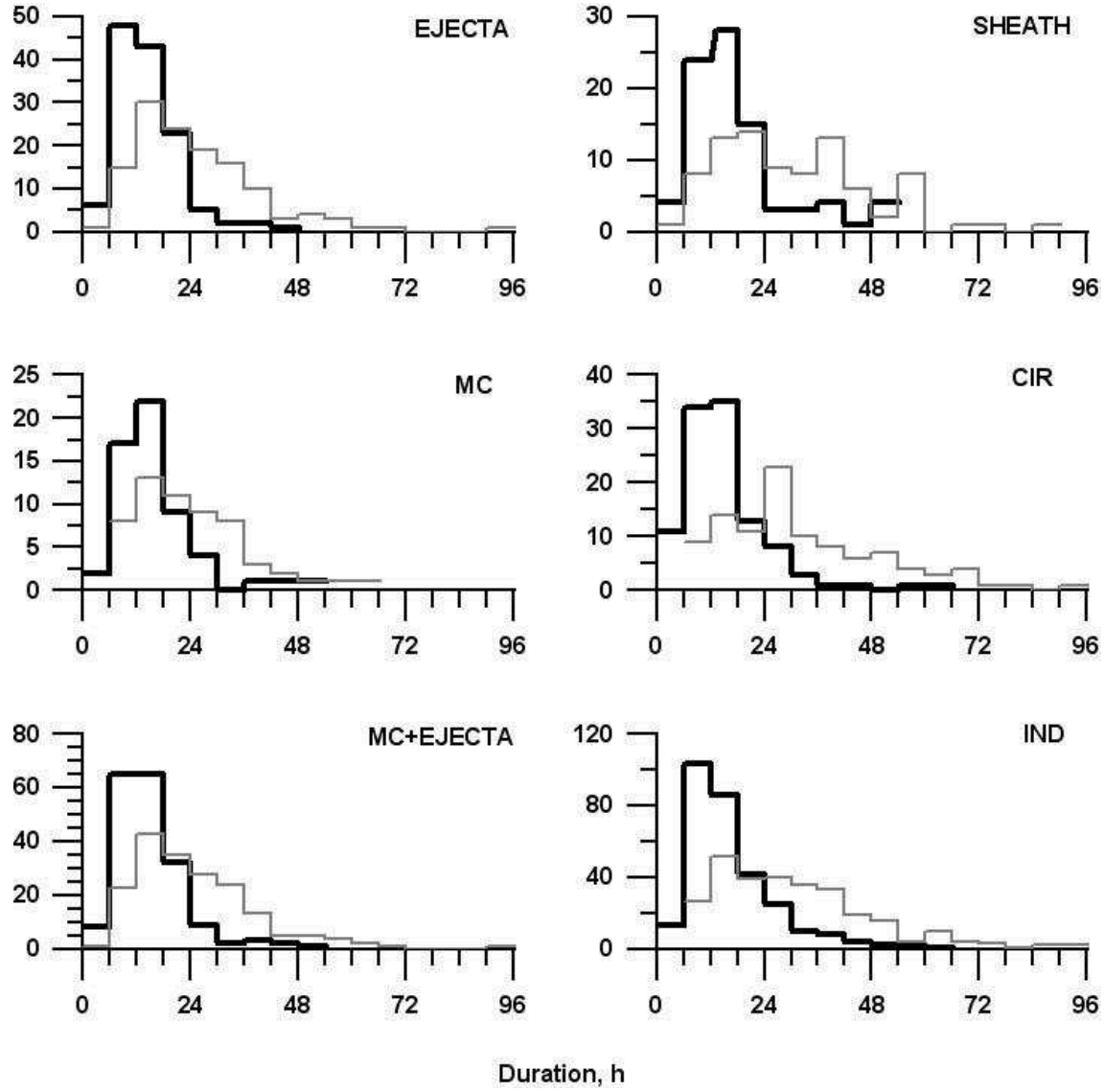
for moderate and strong magnetic storms induced by various drivers

Types of driver	$-100 \leq Dst_{min} < -50$						$Dst_{min} < -100$	
	$(0 - 11)h^*$		$(0 - 18)h^*$		$(0 - 48)h^*$		$(0 - 48)h^*$	
	a, nT	$\tau_h$ , h	a, nT	$\tau_h$ , h	a, nT	$\tau_h$ , h	a, nT	$\tau_h$ , h
IND	-68.4	14.97	-66.3	18.62	-59.2	35.46	-141.5	17.95
CIR	-66.4	15.43	-65.0	18.05	-59.2	29.94	-144.1	19.69
EJE	-70.1	13.39	-69.6	14.05	-58.8	32.36	-135.1	15.72
MC	-71.5	16.26	-71.7	16.08	-60.0	42.74	-154.3	16.95
ME	-70.4	14.05	-70.1	14.54	-59.0	34.72	-142.8	16.23
SHE	-69.0	17.15	-65.8	25.25	-59.5	48.31	-148.8	22.37

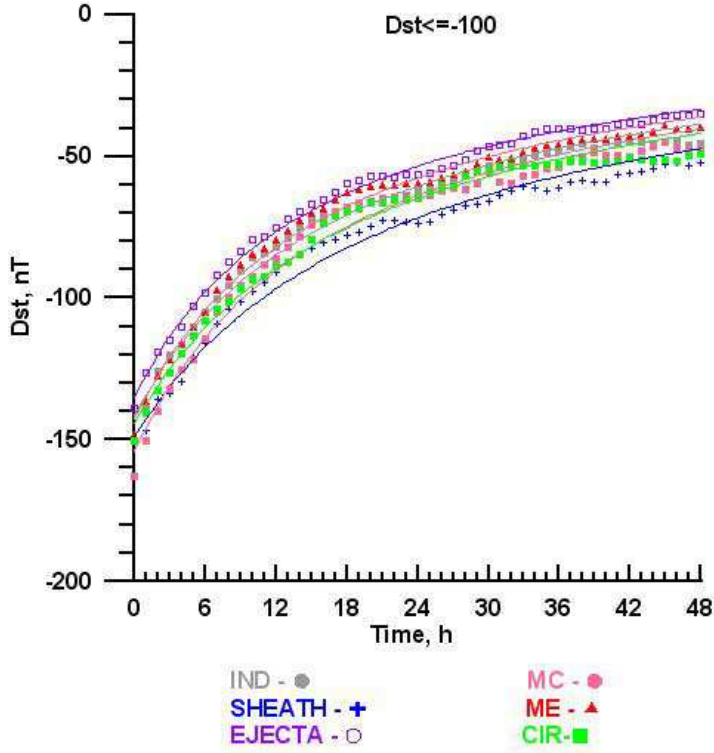
\* Time interval of approximation.

Yermolaev, Yu.I., I.G. Lodkina, N.S. Nikolaeva, M.Yu. Yermolaev, (2012), Geoeffectiveness and efficiency of CIR, Sheath and ICME in generation of magnetic storms, J. Geophys. Res., 2012, in press (this issue)

Zhang, J., Richardson, I. G., Webb, D. F., Gopalswamy, N., Huttunen, E., Kasper, J. C., Nitta, N. V., Poomvises, W., Thompson, B. J., Wu, C.-C., Yashiro, S., and Zhukov, A. N. (2007), Solar and interplanetary sources of major geomagnetic storms ( $Dst < -100$  nT) during 1996–2005, J. Geophys. Res., 112, A10102, doi:10.1029/2007JA012321.

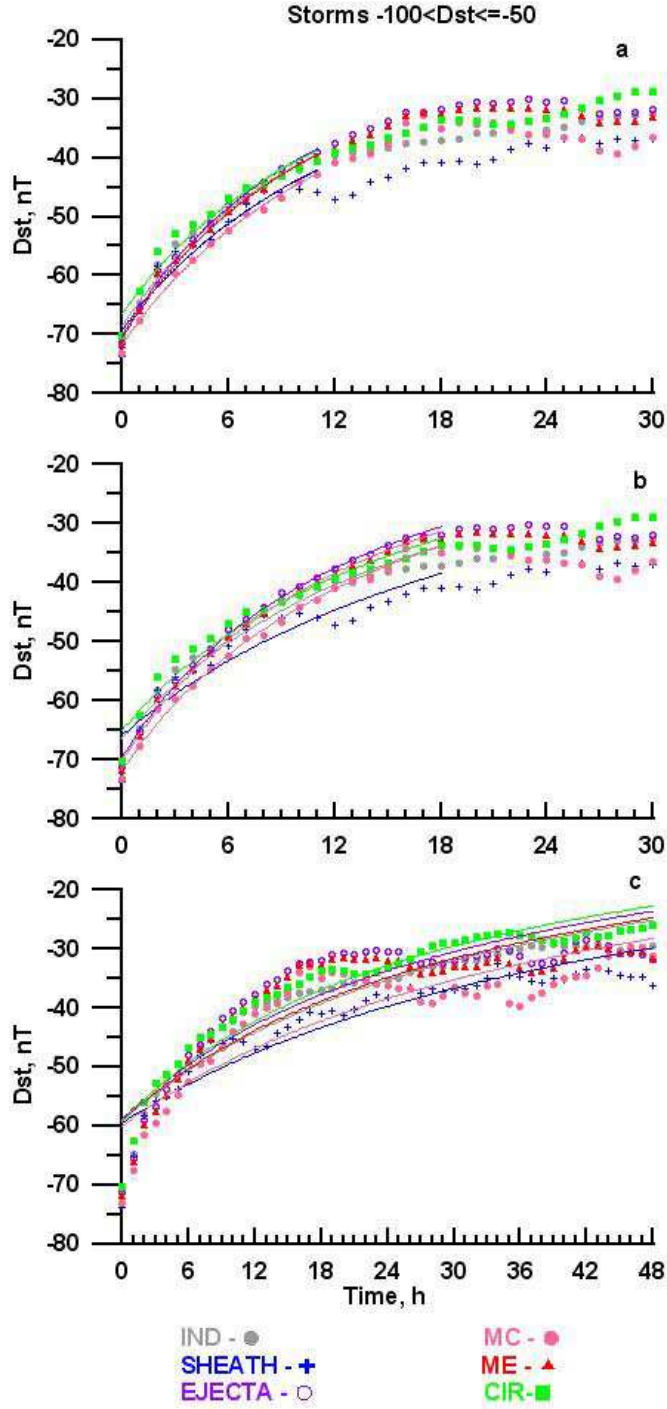


**Figure 1.** Distributions of magnetic storm recovery durations  $\Delta t_{1/2}$  (black line) and  $\Delta t_{1/3}$  (gray line) for different types of interplanetary drivers

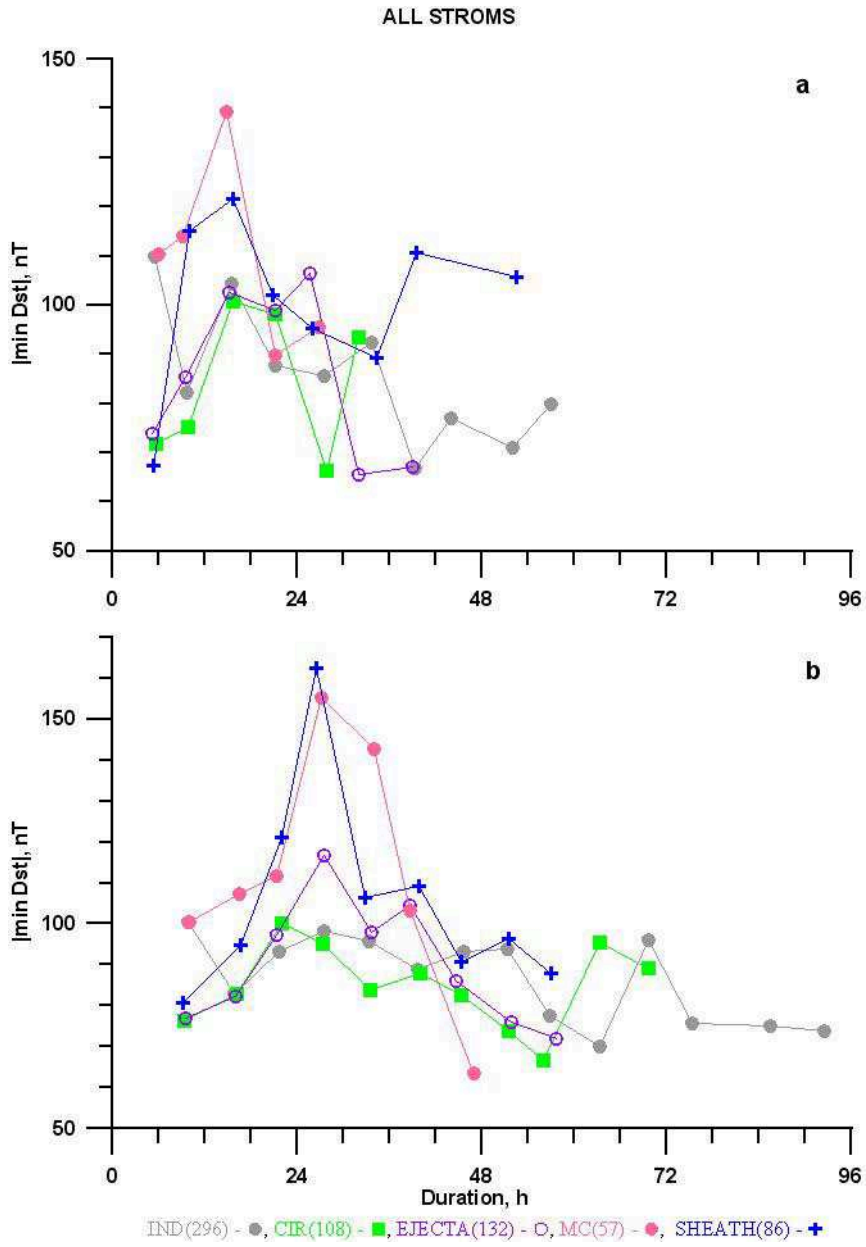


**Figure 2.** Temporal evolution of recovery phases of strong ( $Dst_{min} < -100$  nT) storms induced by various types of drivers (points) and hyperbolic approximations in time intervals of 0–48 hours.





**Figure 3.** Temporal evolution of recovery phases of moderate ( $-100 < Dst_{min} < -50$  nT) storms induced by various types of drivers (points) and hyperbolic approximations in time intervals of (a) 0–11 hours, (b) 0–18 hours, and (c) 0–48 hours.



**Figure 4.** Dependence between  $Dst_{min}$  and duration of recovery phase of magnetic storms induced by various types of drivers: (a) for  $\Delta t_{1/2}$  and (b) for  $\Delta t_{1/3}$